**Exploring Genetic Variability in Segregating generations and Biparental progenies for Sustainable Crop Improvement in Bhendi [*Abelmoschus esculentus* (L.) Moench]**

**ABSTRACT**

To assess the degree of genetic variability, heritability, and genetic advance for Economically important traits in bhendi (*Abelmoschus esculentus* (L.) Monech.), three populations such as BIP, F2, and F3 were developed in bhendi during 2022 and analyzed in 2023. On comparing BIP populations to F2 and F3 populations, significant variation was seen for the majority of the characters. This was supported by high means and wider ranges of variation, which were shown by high to moderate PCV and GCV values for fruit length, number of fruits per plant, and fruit yield per plant. The BIPs of Basanthi / Parbhani Kranti recorded high mean performance for traits such asnumber of fruits per plant, fruit length, fruit girth, fruit yield per plant. The superiority of BIPs developed in all the three crosses could be used as base population for developing high yielding early maturing cultivars as they had combined superior performance for earliness and fruit yield per plant. The analysis of components of variance in BIPs in all the three crosses revealed that the additive genetic variance was predominant, which indicated that selection in early intermating generations could result in development of potential progenies.

**Key words:** Bhendi, Genetic variability, Heritability, Genetic Advance and Biparental Progenies.

**INTRODUCTION**

Bhendi (*Abelmoschus esculentus* (L.) Moench), a member of the Malvaceae family, is a vital vegetable crop cultivated widely for its tender, nutritious fruits that are rich in iodine, vitamins, and essential minerals. It holds significant economic and nutritional value and is consumed globally in various culinary forms. Beyond its role in food security, bhendi also has industrial applications, thereby escalating its overall demand. However, the increasing population pressure and limited cultivable land pose substantial challenges to enhancing production through conventional means. To meet the rising demand, it is imperative to explore genetic improvement strategies that maximize yield potential without requiring additional land resources.

The primary objective of the present study is to enhance the genetic base and develop high-yielding bhendi genotypes through effective breeding strategies. This involves disrupting undesirable linkages and promoting favorable recombination in early segregating generations. Among the available methods, biparental mating proves to be a promising approach, particularly under conditions where additive genetic variance must be exploited efficiently. The biparental mating approach, especially when employed under the framework of North Carolina Design I, enables precise estimation of additive and dominance variance, and facilitates the identification of superior recombinants early in the breeding cycle (Comstock & Robinson, 1952; Singh & Narayanan, 2010). Therefore, the present investigation employs biparental mating in early segregating generations to generate genetically diverse and agronomically superior progenies. This methodology not only supports the recombination of desirable alleles but also aids in accelerating the development of improved bhendi cultivars suitable for sustainable agriculture.

**MATERIALS AND METHODS**

**Experimental Location**

This investigation was conducted at the Plant Breeding Farm, Department of Genetics and Plant Breeding, Annamalai University, Tamil Nadu, India. The experimental site is geographically located at 11.39° N latitude and 79.70° E longitude, with an altitude of approximately 5.79 meters above mean sea level. The study period extended from October 2023 to July 2024, with earlier generations maintained between October 2017 and January 2018.

**Experimental Materials**

The experimental material comprised F₂ seeds of three cross combinations along with their respective parental lines. These were sourced from the germplasm repository maintained by the Department of Genetics and Plant Breeding, Annamalai University. The three cross combinations included:

* Cross 1: Hisar Unnat × Parbhani Kranti
* Cross 2: Kranti Ankur 40 × Hisar
* Cross 3: Unnat Basanthi × Parbhani Kranti

Approximately 200 F₂ plants from each of the three cross combinations were grown under non-replicated trial conditions with a spacing of 45 cm between rows and 30 cm between plants. The experiment followed standard agronomic practices throughout the crop season, including timely irrigation, weeding, and the application of need-based plant protection measures.

To generate the F₃ generation, the F₂ plants were selfed, and seeds were collected individually from each plant. Sufficient quantities of F₂ seeds were also preserved for raising the F₂ population in the subsequent season to facilitate comparative analysis of F₂, F₃, and Biparental Progenies (BIPs). BIPs were developed by intermating randomly selected F₂ plants, designated separately as males and females. In each cross combination, four male plants were randomly chosen and labelled. Each male plant was crossed with four distinct female plants, with care taken to avoid reusing any female plant across different male combinations. This strategy ensured genetic diversity and minimized parental overlap.

**Pollination and Seed Harvest**

Pollination was carried out manually, and each cross was protected using butter paper covers a day prior to anthesis to ensure controlled fertilization. After the crosses were made, the remaining F₂ plants were self-pollinated similarly to produce F₃ seeds. All harvested seeds (BIPs and F₃s) were collected separately for further evaluation.

**Data Collection**

Morphological and yield-related traits were recorded from individual F₂, F₃, and BIP plants. Observations included both quantitative traits (such as plant height, fruit length, number of fruits per plant, fruit weight, and total yield per plant).

**Experimental Design and Statistical Analysis**

Though the trial was non-replicated, randomization was followed within each cross block. The data were subjected to analysis of variance (ANOVA) to assess genetic variability among generations. Mean, standard deviation, phenotypic and genotypic coefficients of variation (PCV and GCV), heritability (broad sense), genetic advance, and correlation coefficients were estimated following the procedures of Burton and DeVane (1953) and Johnson et al. (1955). For biparental progenies, additional analysis was done using North Carolina Design I to estimate additive and dominance variance components.

**RESULT AND DISCUSSION**

According to the Analysis of Variance (ANOVA) of BIPs, there were significant variations between the male and female parents for practically every characteristic in every cross that was studied. for the character no of fruits per plant, among the three crosses BIPs of cross 2 showed maximum range (9.00-28.00). The maximum mean value (24.20) was registered in BIPs of cross 3 followed by BIPs of cross 2. Here BIPs of all the crosses recorded high mean values when compared to F2’s and F3’s of corresponding crosses. for the character fruit length, the widest range (9.00-21.00 cm) was recorded in F2’s of cross 1. On comparing the mean values of F2’s, F3’s and BIPs of all the crosses BIPs of cross 2 exhibited maximum mean value (19.25 cm) followed by BIPs of cross 3. For the character fruit yield per plant, maximum range in BIPs of cross 2 (190.00-620.00 g). The maximum mean value for this trait was recorded in BIPs of cross 3 (439.25 g) followed by BIPs of cross 1 (434.00 g). “Comparison of mean and range of different characters between biparental (BIPs) and selfed progenies indicated that the mean and range values of BIPs were higher than that of selfed progenies for all the characters studied. The superior means and wider ranges in the biparental progenies may be due to releasing of hidden genetic variability in F2 progenies” (Somashekhar guddadamath, 2009). The *per se* performance revealed that the BIPs of cross 3 recorded superior performance for characters *viz.,* number of fruits per plant, fruit length and fruit yield per plant when compared to other crosses. This is followed by BIPs of cross 2, which recorded next best performance for the traits *viz.,* number of fruits per plant, fruit length, fruit girth and fruit yield per plant. In general, BIPs recorded superior mean performance than F3’s for most of the characters studied. This is due to that “rare recombinants which remain restricted due to linkage disequilibrium are promptly released by forced recombination and become available for selection in early segregating generations” (Koli *et al*. 2018). The range and mean performance of the parents, F2’s, F3’s and BIPs for the traits studied in Bhendi were tabulated in Table 1 to Table 3. The comparison of PCV and GCV in BIPs, F2’s and F3’s population for seven traits showed that estimates of PCV were generally high than GCV for all the characters studied. It denotes that the environmental factors influencing the expression to some degree which is in accordance with findings of Saryam *et al*. (2015) and Jadhav *et al*. (2016). For the trait Number of fruits per plant, Moderate to high PCV and GCV were recorded for this trait in all the crosses studied. Maximum value of PCV was recorded in F2’s of cross 1 (38.32). BIPs of cross 3 (29.42) showed maximum value for GCV. BIPs of all the crosses showed superiority over F3’s for all the crosses. BIPs of cross 2 (79.42) recorded high heritability and BIPs of cross 3 (54.65) recorded maximum genetic advance as per cent of mean for the trait Fruit length, Moderate to high PCV and GCV were recorded in all the crosses studied. Maximum value of PCV was recorded in F2’s of cross 1 (29.30) and maximum value for GCV was recorded in BIPs of cross 3 (28.85). BIPs of cross 3 registered high heritability (89.45) and high genetic advance as per cent of mean (50.78). For the trait Fruit yield per plant, recorded Moderate to high PCV and GCV for all the crosses. Maximum value PCV (23.57) and high GCV (19.85) was recorded in BIPs of cross 3. Maximum value of heritability (90.52) and genetic advance as per cent of mean (33.85) was also recorded in BIPs of cross 3. BIPs of all the crosses recorded high values for genetic advance as per cent of mean when compared to F2’s and F3’s of corresponding crosses. Biparental mating populations showed high PCV and GCV values than F2’s and F3’s for most of the traits *viz.,* days to 50 per cent flowering, plant height, number of fruits per plant, fruit length and fruit yield per plant of cross 3 followed by BIPs of cross 2. The increased genetic variability not available in F3 populations was released in BIP due to intermating of F2 plants. It is also quite interesting to note that the difference between PCV and GCV has been narrowed down in BIPs compared to F3’s, thus indicated that selection could be done directly based on phenotype itself, which is the reflection of the genotype. This narrowed down differences may be due to the accumulation of favorable genes and breaking down of undesirable linkages due to intermating. And it is observed that cross 3 recorded high heritability coupled with high genetic advance as per cent of mean in BIPs for the traits *viz.,* number of fruits per plant, fruit length, fruit girth and fruit yield per plant. In cross 2 traits such as number of fruits per plant and fruit yield per plant recorded high heritability coupled with high genetic advance as per cent of mean. It indicated that in general BIPs recorded moderate to high heritability and genetic advance as per cent of mean for most of the characters, which indicates the additive gene action and simple phenotypic selection may be practiced to improve these characters. Thus, the result obtained was similar to that of result obtained by Deo (2014), Khajuria *et al*. (2015), Kerure *et al*. (2017), Kumar et al. (2019), Singh et al. (2020), Shwetha et al. (2022) and Nanditha et al. (2023). The genetic variability parameters in F2’s, F3’s and BIPs for traits studied in Bhendi were tabulated from Table 4 to Table 6 (Fig. 1).

**CONCLUSION**

It is observed that, The BIPs of Basanthi / Parbhani Kranti recorded high mean performance for traits such asinternode length, number of fruits per plant, fruit length, fruit girth, fruit yield per plant. The superiority of BIPs developed in all the three crosses could be used as base population for developing high yielding early maturing cultivars as they had combined superior performance for earliness and fruit yield per plant. The analysis of components of variance in BIPs in all the three crosses revealed that the additive genetic variance was predominant, which indicated that selection in early intermating generations could result in development of potential progenies.

According to the variability study, the BIPs of Basanthi and Parbhani Kranti had a moderate GCV and a high PCV for fruit output per plant. PCV and GCV were low to high for all other characteristics. However, for practically all of the features under study, BIPs generally showed greater PCV and GCV values than F3s. The breakdown of the linkage group resulting from the intermating of early segregating generations may be the cause of this diversity in BIPs. High heritability coupled with high genetic advance as per cent of mean was observed in BIPs of Basanthi / Parbhani Kranti for the traits *viz.,* number of fruits per plant, fruit length, fruit yield per plant which revealed the importance of additive gene action for these traits. Presence of low to moderate PCV and GCV coupled with high heritability and genetic advance as per cent of mean for these traits indicated the presence of both additive and non-additive gene action (dominance and epistasis).

**Disclaimer on Artificial intelligence**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models and text-to-image generators have been used during the writing or editing of this manuscript.

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**Table 1. Range and mean performance of parents, F2’s, F3’s and BIPs for number of fruits per plant in Bhendi**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parents / Generation** | **Cross 1** | **Cross 2** | **Cross 3** | **General mean** |
| P1 | Range | 15.00-25.00 | 14.00-20.00 | 15.00-24.00 | 14.96 |
| Mean | 15.60 | 13.20 | 16.10 |
| P2 | Range | 14.00-22.00 | 15.00-20.00 | 13.00-18.00 | 18.43 |
| Mean | 21.00\*\* | 15.10 | 19.20\* |
| F2 | Range | 12.00-20.00 | 11.00-25.00 | 6.00-22.00 | 20.55 |
| Mean | 18.25\* | 23.30\*\* | 20.10\* |
| F3 | Range | 12.00-31.00 | 6.00-23.00 | 15.00-26.00 | 21.36 |
| Mean | 21.50\*\* | 20.10\*\* | 22.50\*\* |
| BIPs | Range | 8.00-26.00 | 9.00-28.00 | 12.00-29.00 | 23.58 |
| Mean | 23.05\*\* | 23.50\*\* | 24.20\*\* |

**Table 2. Range and mean performance of parents, F2’s, F3’s and BIPs for fruit length (cm) in Bhendi**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parents / Generation** | **Cross 1** | **Cross 2** | **Cross 3** | **General mean** |
| P1 | Range | 12.00-14.00 | 13.00-16.00 | 9.00-12.00 | 11.90 |
| Mean | 13.00 | 13.50 | 9.20 |
| P2 | Range | 9.50-15.00 | 8.00-14.00 | 9.40-14.00 | 12.30 |
| Mean | 13.50\* | 9.60 | 13.80 |
| F2 | Range | 9.00-21.00 | 11.00-17.00 | 8.00-18.00 | 14.57 |
| Mean | 15.60\*\* | 12.40 | 15.70\* |
| F3 | Range | 7.00-17.00 | 8.60-18.00 | 8.00-19.00 | 16.20 |
| Mean | 14.90 | 15.80\*\* | 17.90\*\* |
| BIPs | Range | 18.00-26.00 | 16.00-27.00 | 16.00-22.00 | 17.72 |
| Mean | 15.90\*\* | 19.25\*\* | 18.00\*\* |

**Table 3. Range and mean performance of parents, F2’s, F3’s and BIPs for fruit yield per plant (g) in Bhendi**.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parents / Generation** | **Cross 1** | **Cross 2** | **Cross 3** | **General mean** |
| P1 | Range | 200.00-290.00 | 295.00-450.00 | 250.00-306.00 | 299.53 |
| Mean | 230.00 | 392.90 | 275.70 |
| P2 | Range | 220.00-300.00 | 200.00-340.00 | 220.00-350.00 | 261.67 |
| Mean | 260.00 | 245.00 | 280.00 |
| F2 | Range | 420.00-570.00 | 430.00-670.00 | 370.00-560.00 | 430.43 |
| Mean | 430.00\*\* | 440.70\*\* | 420.60 |
| F3 | Range | 230.00-560.00 | 200.00-567.00 | 320.00-560.00 | 418.82 |
| Mean | 410.60 | 412.06 | 433.80\*\* |
| BIPs | Range | 300.00-600.00 | 190.00-620.00 | 220.80-640.00 | 431.20 |
| Mean | 434.00\*\* | 420.35\*\* | 439.25\*\* |

\*Significant at 5 per cent level \*\*Significant at 1 per cent level

**Table 4. Genetic variability parameters in F2’s, F3’s and BIPs for number of fruits per plant in Bhendi.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Crosses** | **Population** | **PCV****(per cent)** | **GCV****(per cent)** | **Heritability (per cent)** | **Genetic Advance** | **Genetic Advance as per cent of mean** |
| Cross 1 | F2 | 38.32 | 27.23 | 67.91 | 7.04 | 50.72 |
| F3 | 31.24 | 27.14 | 68.52 | 6.96 | 45.73 |
| BIPs | 28.93 | 27.91 | 79.31 | 6.59 | 46.31 |
| Cross 2 | F2 | 34.56 | 27.85 | 64.82 | 5.78 | 44.74 |
| F3 | 26.74 | 20.31 | 66.72 | 5.67 | 35.62 |
| BIPs | 31.53 | 23.53 | 79.42 | 6.93 | 50.61 |
| Cross 3 | F2 | 32.64 | 26.74 | 53.81 | 5.42 | 35.82 |
| F3 | 28.54 | 18.54 | 46.81 | 3.65 | 25.76 |
| BIPs | 32.67 | 29.42 | 79.23 | 7.20 | 54.65 |

**Table 5. Genetic variability parameters in F2’s, F3’s and BIPs for fruit length in Bhendi**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Crosses** | **Population** | **PCV****(per cent)** | **GCV****(per cent)** | **Heritability (per cent)** | **Genetic Advance** | **Genetic Advance as per cent of mean** |
| Cross 1 | F2 | 29.30 | 24.97 | 71.57 | 5.79 | 41.56 |
| F3 | 16.40 | 8.90 | 23.53 | 0.98 | 8.69 |
| BIPs | 28.32 | 26.75 | 84.26 | 7.32 | 48.89 |
| Cross 2 | F2 | 15.63 | 1.02 | 0.53 | 0.09 | 0.09 |
| F3 | 28.90 | 26.32 | 81.54 | 7.23 | 42.00 |
| BIPs | 11.94 | 4.21 | 14.52 | 0.64 | 2.90 |
| Cross 3 | F2 | 15.63 | 5.20 | 11.41 | 0.78 | 3.53 |
| F3 | 15.69 | 11.49 | 50.63 | 1.95 | 16.89 |
| BIPs | 29.10 | 28.85 | 89.45 | 8.17 | 50.78 |

**Table 6. Genetic variability parameters in F2’s, F3’s and BIPs for fruit yield per plant in Bhendi.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Crosses** | **Population** | **PCV****(per cent)** | **GCV****(per cent)** | **Heritability (per cent)** | **Genetic Advance** | **Genetic Advance as per cent of mean** |
| Cross 1 | F2 | 22.34 | 16.78 | 67.85 | 129.94 | 31.56 |
| F3 | 20.45 | 16.74 | 57.45 | 96.74 | 24.71 |
| BIPs | 22.62 | 17.94 | 78.93 | 134.65 | 31.68 |
| Cross 2 | F2 | 19.98 | 15.56 | 58.52 | 99.56 | 23.54 |
| F3 | 18.87 | 15.79 | 68.87 | 129.86 | 30.75 |
| BIPs | 22.19 | 18.32 | 81.28 | 115.84 | 31.76 |
| Cross 3 | F2 | 17.45 | 16.76 | 73.59 | 132.75 | 28.73 |
| F3 | 16.53 | 13.54 | 72.49 | 97.56 | 23.75 |
| BIPs | 23.57 | 19.85 | 90.52 | 149.96 | 33.85 |

**Figure 1. PCV, GCV, Heritability and GA as per cent Mean for all the Crosses**

